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FRONT END DESIGN FOR MITIGATION OF PEDESTRIAN HEAD INJURY

HOOD-FENDER REGION

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INTRODUCTION

The National Highway Safety Administration is addressing the pedestrian accident problem in the United States through a number of programs, one of which is the Advanced Pedestrian Protection Program [1]. An analysis of pedestrian accident data indicated that head and thorax injuries account for most of the harm to pedestrians, and that vehicle faces (grilles, headlight areas, leading edges of hoods and fenders) and the top surfaces of hoods and fenders are the major sources of injury. Consequently, a major part of the Advanced Pedestrian Protection Program is to develop methods of reducing adult and child pedestrian head injury due to contact with automobile hoods, fenders, and faces. Thorax injury reduction is the subject of a concurrent study, which is reported in reference 2.

The objective of this paper is to describe the current status of work to develop practical vehicle designs, in the hood/fender region, which reduce adult pedestrian head injury. Techniques for simulating pedestrian head impacts on vehicles with a variable mass surrogate headform impactor and assessing injury severity from impactor response were developed. This was accomplished by reconstructing 14 pedestrian accidents involving adults. Simulated adult pedestrian head impacts were performed on current production cars with the impactor. These production car tests were conducted to 1) determine the head injury potential of the hood/fender impact region, and 2) understand how specific geometric and/or material characteristics at the hood/fender interface influence injury severity and might be altered to reduce the severity of head impacts. Based on results found from the production car analysis, injury reduction tests were initiated. These tests were used to determine the optimal geometric and material combination design for the hood/fender region which is least injurious to adult pedestrians. An underlying theme present during all the research was that any design modification intended to reduce pedestrian head injury must be practical and production feasible [3].

SURROGATE HEADFORM IMPACTOR

The surrogate headform impact device, shown in Figure 1, uses pneumatic pressure to accelerate the impacting ram and headform. The impacting ram is a free projectile confined to uniaxial motion. The headform, as seen in Figure 2, is a variable mass semi-spherical aluminum fixture covered with Hybrid III dummy skin [3,4].

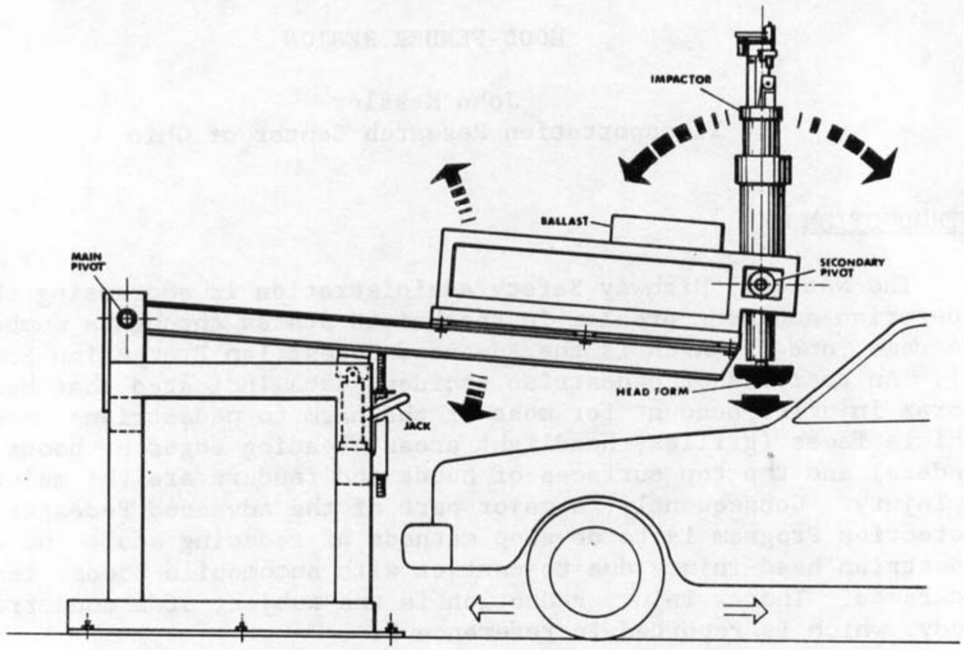

FIGURE 1 VRTC PEDESTRIAN HEAD IMPACT SIMULATOR

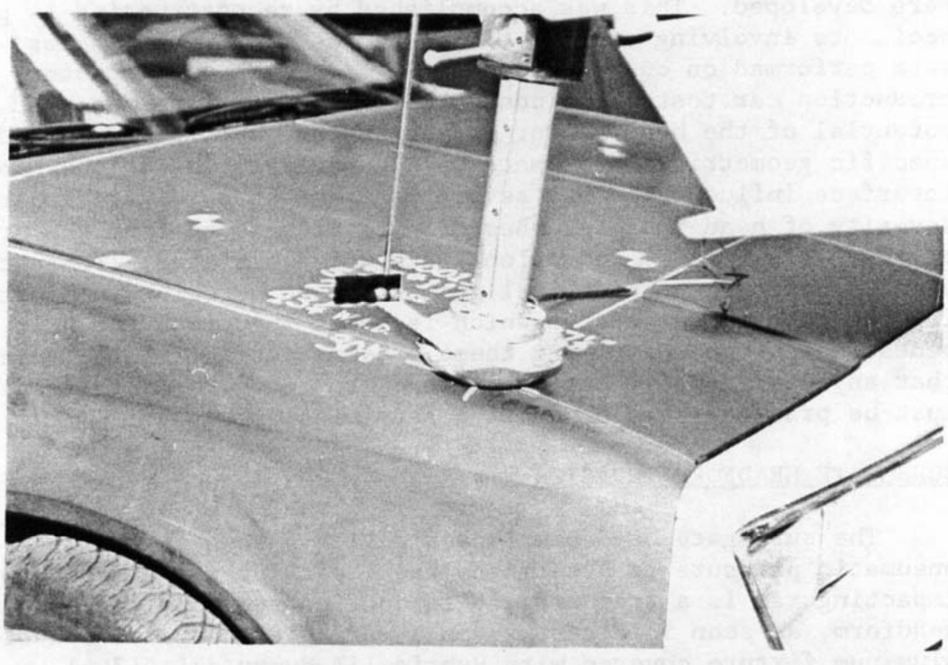

FIGURE 2 VARIABLE MASS HEADFORM OF THE HEAD IMPACT SIMULATOR

ADULT PEDESTRIAN ACCIDENT RECONSTRUCTIONS

In order to predict head injury severity from measured impactor response, 14 adult pedestrian accidents were reconstructed. That is, the vehicle damage, or dent, caused by each head impact was accurately duplicated in each test. It was found that this could only be done if both the effective head mass and head impact velocity were closely simulated [3,5].

The 14 adult cases reconstructed were uniformly distributed over a full range of injury severity. Therefore, results from these reconstructions were used to establish a correlation between impactor test responses and the injury severity experienced in the accidents. Injury severity was assessed by determining the probability of death from the three most severe head injuries for each of the 14 accident victims [8]. The Translational Mean Strain Criterion (TMSC) [6,7], calculated from the impactor responses, was found to correlate well with the probability of death determined for the accident victims. Probability of death is plotted against TMSC in Figure 3 [3,5].

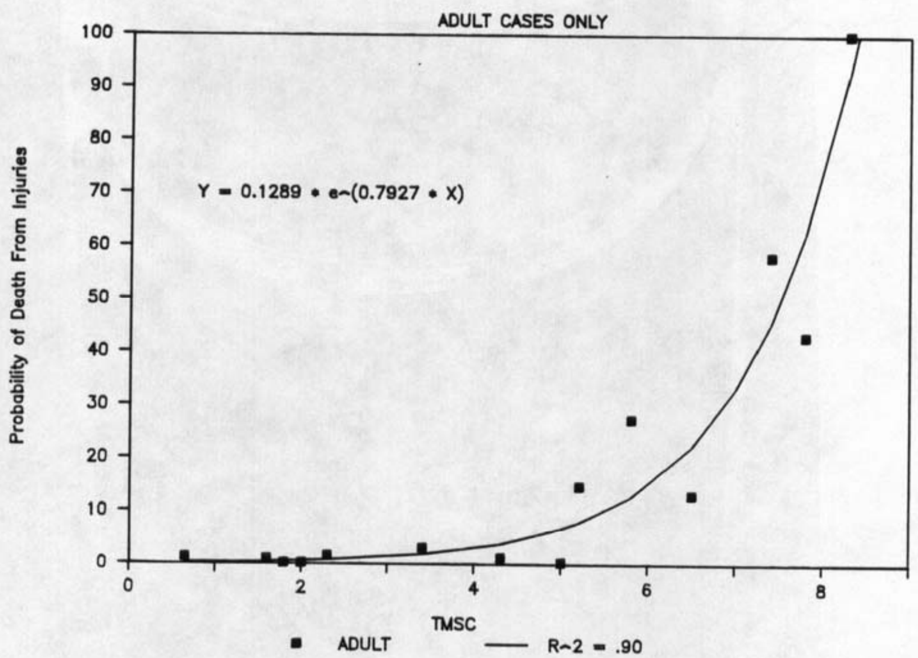

FIGURE 3 VARIATION OF PROBABILITY OF DEATH WITH TMSC FOR THE ADULT RECONSTRUCTIONS

PRODUCTION CAR TESTS

Following the adult accident reconstructions, a series of simulated pedestrian head impacts on current production cars were performed. Specifically, production car tests were conducted to determine head injury potential of common hood and fender impact regions and to understand how particular geometric and/or material characteristics influence injury severity [3].

The primary criterion for the selection of vehicles for production car head impact testing was that they represent a reasonable cross-section of the current U.S. car fleet. Vehicle size, popularity, styling and unique design design features were also considered. For example, hood/fender region tests included cars with conventional hood/fender designs and "full-cover" hood designs. Certain cars, such as the 1983 Saab 900, have hoods that cover the entire width of the vehicle, thus placing the hood/fender seam on the side of the car, an area generally not involved in pedestrian impacts. The Saab 900 "full-cover" hood is shown in Figure 4. Figure 5 shows a 1985 Oldsmobile Ciera which has the more conventional hood/fender seam location on top. Both designs were tested to determine if the "full-cover" design provided a significant advantage over conventional hood/fender design. The vehicles used in the production car study are listed in Table 1 [3].

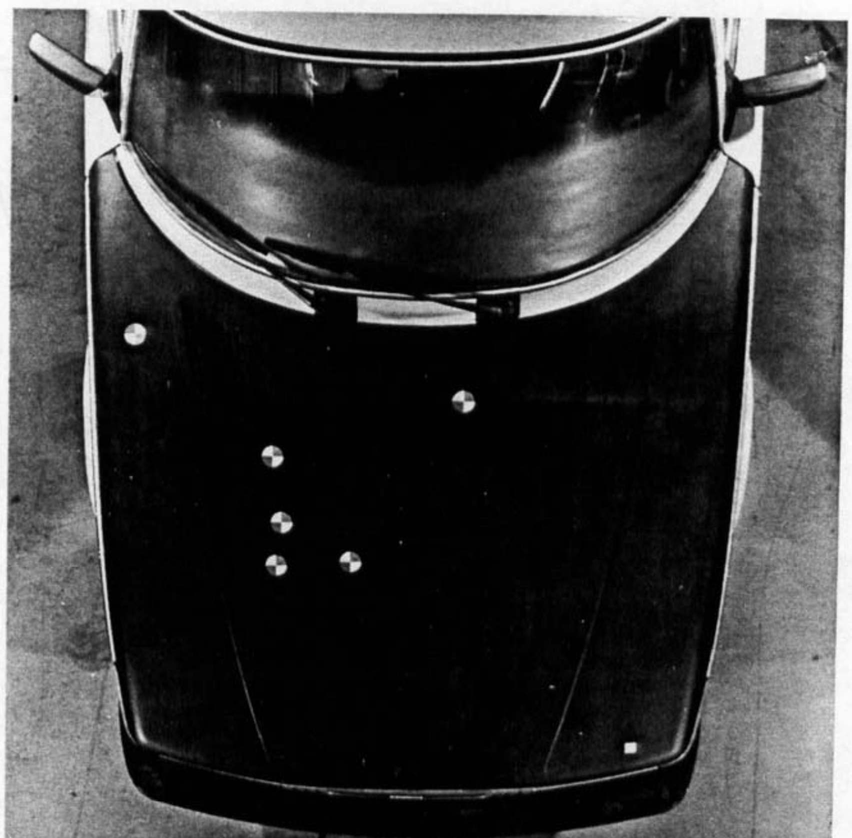

FIGURE 4 1983 SAAB 900

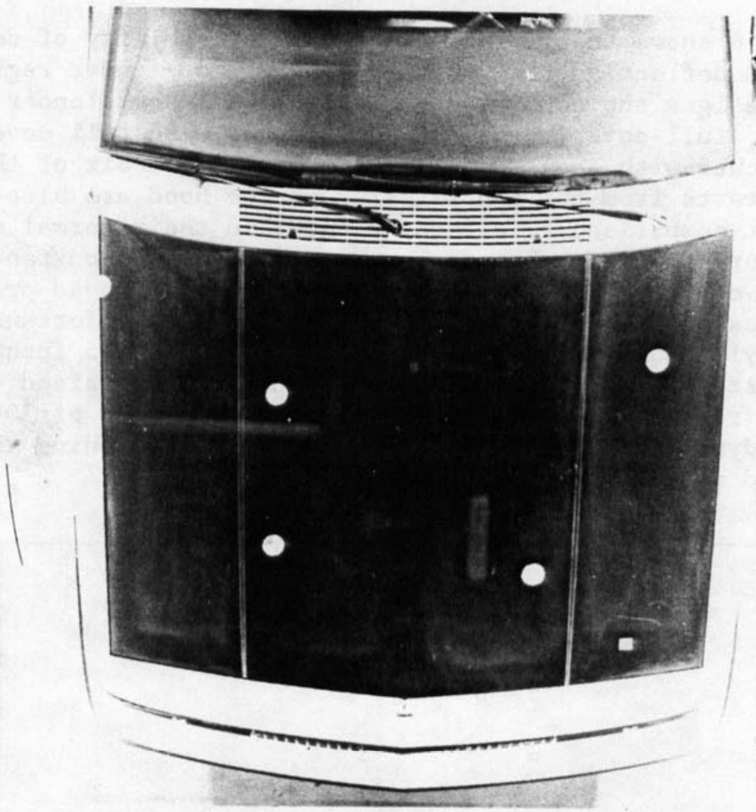

FIGURE 5 1985 OLDSMOBILE CIERA

TABLE 1 PRODUCTION TEST VEHICLES

VEHICLE REGION/DESIGN TESTED	VEHICLES USED
HOOD AND CONVENTIONAL HOOD/FENDER SEAM LOCATION	1985 FORD ESCORT 1983 CHEVROLET CHEVETTE 1985 PONTIAC GRAND AM 1983 FORD THUNDERBIRD 1983 SAAB 900 1985 CHRYSLER LEBARON GTS 1985 PONTIAC SUNBIRD 1982 CHEVROLET CAVALIER 1985 OLDSMOBILE CIERA 1984 CHEVROLET CELEBRITY 1985 FORD MUSTANG SVO 1985 PONTIAC FIERO 1983 CHEVROLET CAPRICE
FULL-COVER HOOD	1983 SAAB 900 1983 RENAULT ALLIANCE 1983 ISUZU IMPULSE 1986 BUICK ELECTRA

Figure 6 shows the variation in adult probability of death with dynamic hood deflection from impacts in the hood/fender region for the following designs and conditions: conventional hood/fender seams, full-cover hoods, full-cover hoods raised 4 inches, and full-cover hoods raised 4 inches with edge reinforcements removed. Six of the best production tests from the central area of the hood are also listed on Figure 6 for comparison. Full-cover hoods in their normal configuration show no injury reduction benefit over conventional hood/fender designs. Raised full-cover hoods with edge reinforcements removed predicted probabilities of death less than 10% when tested. Unfortunately, these tests also yielded unrealistic hood deflections of 3.5 inches or more. However, test 382 (on an un-altered full-cover hood raised 4 inches) predicted a relatively low probability of death value of 30% with a more reasonable dynamic deflection of 2.75 inches, approaching the best central hood area results [3].

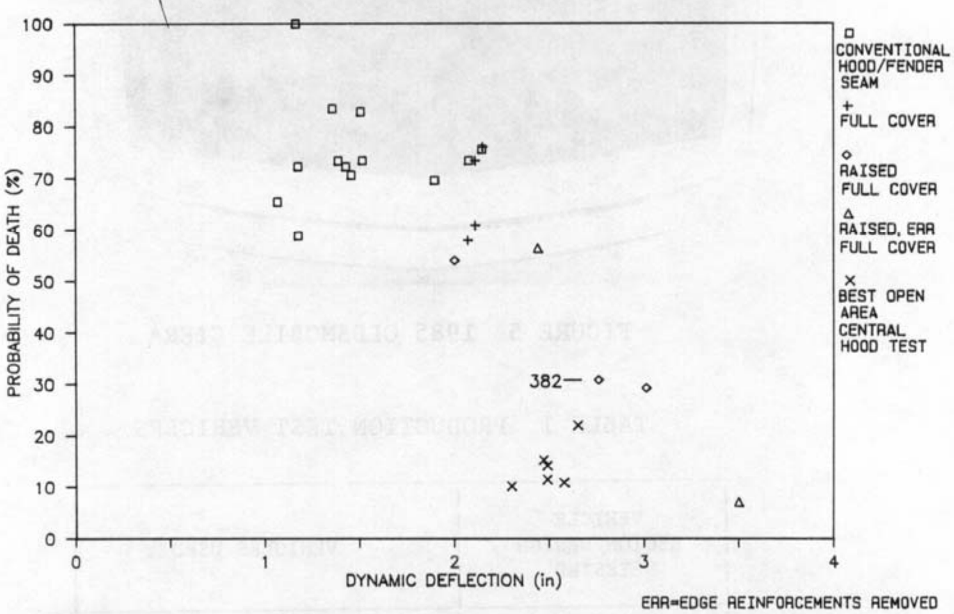

FIGURE 6 VARIATION OF PROBABILITY OF DEATH WITH DYNAMIC HOOD DEFLECTION FOR THE HOOD-FENDER REGION - ADULT TESTS

"FULL-COVER" DESIGN DEVELOPMENT FOR INJURY REDUCTION

Results from the production car hood/fender region testing indicated that the "full-cover" hood design offered the potential to reduce pedestrian head injury in that area. This prompted an investigation to determine a design to reduce injury. The analysis focused on a region of the hood/fender area that adults commonly impact. Figure 7 illustrates the region of interest (indicated by a dashed line on the 1983 Saab 900) and Figure 8 shows a schematic cross-sectional view of the region. The design parameters which were varied are also listed in Figure 8. The length (L), radius (R), and angle (theta) values listed are the upper and lower limits of the range of values determined to be reasonable hood dimensions. The four values listed for the thickness (t) represent and bound the sheet metal thicknesses seen in the current car fleet. Sixteen aluminum and 16 steel specimens were to be tested originally. All specimens were impacted with a 7.9 pound headform at 27 miles per hour at the impact location shown in Figure 8. Figure 9 shows a test specimen in position ready to be impacted.

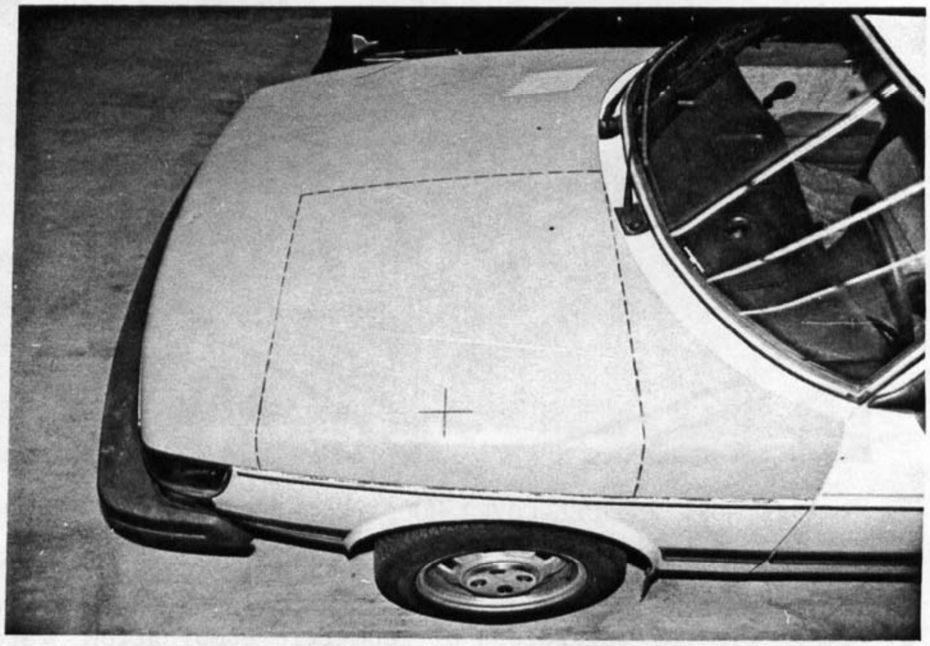

FIGURE 7 1983 SAAB 900

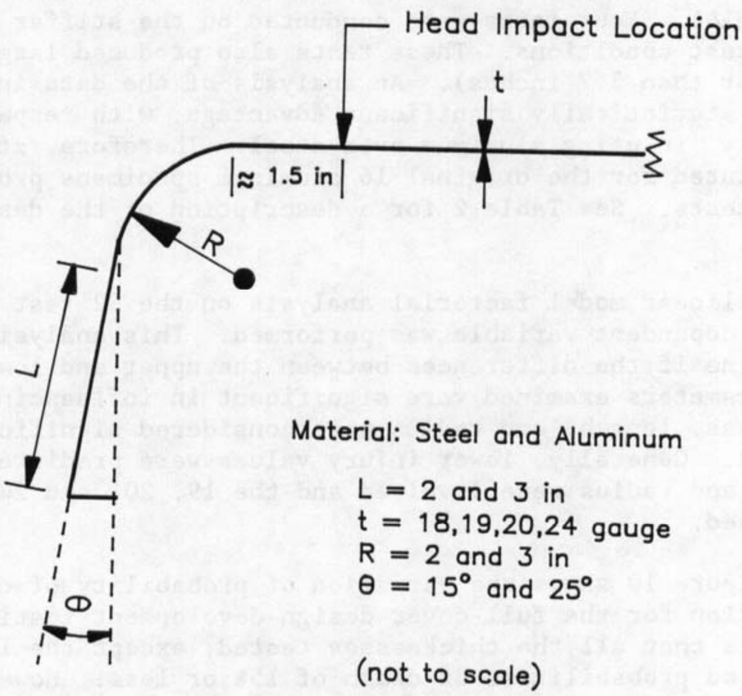

FIGURE 8 CROSS SECTIONAL VIEW OF FULL-COVER HOOD-FENDER REGION

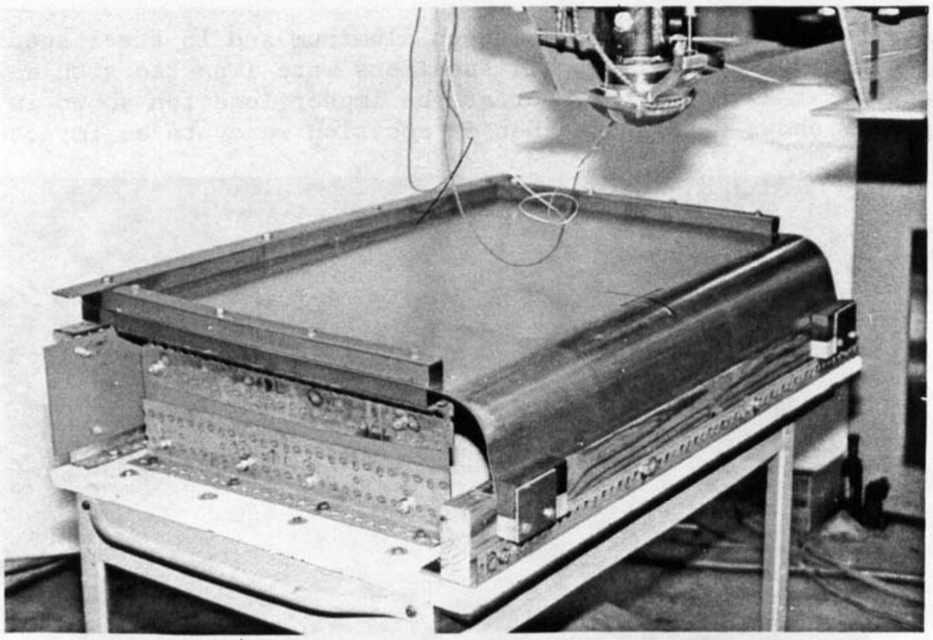

FIGURE 9 FULL-COVER HOOD PROTOTYPE TEST SPECIMEN

It was determined midway through the testing, however, that aluminum specimens, regardless of geometric combination, were impractical. Results indicated that the aluminum permitted unreasonable hood deflections (greater than 3.9 inches). An effort was made to substitute a stiffer aluminum (6061-T6) for the one originally chosen (3003-H14). Four tests were conducted on the stiffer aluminum under the given test conditions. These tests also produced large deflections (greater than 3.7 inches). An analysis of the data indicated that there was no statistically significant advantage, with respect to injury severity, in using aluminum over steel. Therefore, steel specimens were substituted for the original 16 aluminum specimens producing a set of 32 steel tests. See Table 2 for a description of the design combinations tested.

A linear model factorial analysis on the 32 test matrix using TMSC as the dependent variable was performed. This analysis was conducted to determine if the differences between the upper and lower limit values of the parameters examined were significant in influencing injury severity. Thickness, length, and radius were considered significant while angle was not. Generally, lower injury values were predicted when the 3 inch length and radius were involved and the 19, 20, and 24 gauge thicknesses were used.

Figure 10 shows the variation of probability of death with dynamic deflection for the full-cover design development testing. Results indicate that all the thicknesses tested, except the 18 gauge steel, predicted probabilities of death of 15% or less. However, only the 19 gauge predicted 15% probabilities of death with reasonable deflections between 2.7 and 3 inches. These tests on specimens 2,4, and 5 are noted on Figure 10. These injury predictions and deflection values closely match those for the best central hood tests shown on Figure 6. The results from the 19 gauge specimen tests represent a significant improvement over the hood/fender region production car tests shown on Figure 6.

TABLE 2 FULL-COVER HOOD DESIGN OPTIMIZATION TEST MATRIX

SPECIMAN No.	RADIUS (R) (inches)	LENGTH (L) (inches)	ANGLE (B) (degrees)	THICKNESS (T) Gauge
1	2	3	15	18,19,20,24
2	2	2	15	18,19,20,24
3	2	3	25	18,19,20,24
4	2	2	25	18,19,20,24
5	3	3	15	18,19,20,24
6	3	2	15	18,19,20,24
7	3	3	25	18,19,20,24
8	3	2	25	18,19,20,24

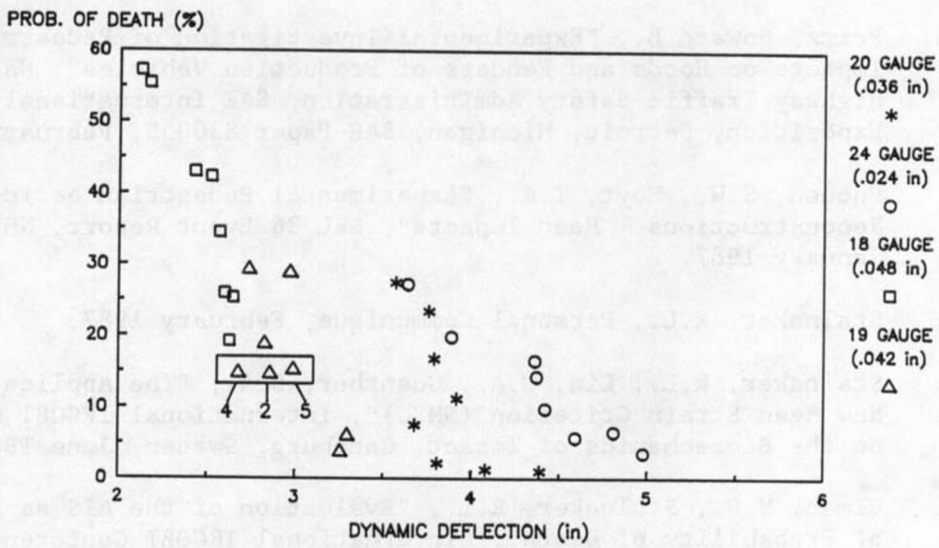

FIGURE 10 VARIATION OF PROBABILITY OF DEATH WITH DYNAMIC DEFLECTION FOR THE FULL-COVER HOOD DESIGN OPTIMIZATION TEST MATRIX

CONCLUSIONS

A rigid variable mass head impact device was developed. Fourteen adult pedestrian accidents were reconstructed and an injury criterion was derived which enables headform test responses to be related to injury severity with a high degree of confidence.

Simulated head impacts on current production vehicles indicated that pedestrian head impacts on conventional hood/fender seam designs and present day "full-cover" hood designs are potentially much more injurious than those on central hood impact locations.

A "full-cover" hood design which incorporates a generous radius and distance above the fender and uses a steel sheet metal thickness of 19 gauge can significantly reduce adult pedestrian head injury severity due to head impacts in the hood/fender region. The modified "full-cover" hood design can potentially enable head injury severity in the hood/fender region to be no worse than that seen in the overall least injurious central hood region.

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DISCUSSION

PAPER: Front End Design for Mitigation of Pedestrian Head Injury

SPEAKER: John Kessler, Transportation Research Center

Q. Claude Tarriere, APR
How do you get the correct values for head mass, and head impact velocities, for the reconstruction that you have done with the impactor?

A. I have a slide that I think might help. This is a plot of permanent hood deflection versus impact energy for a particular location on a particular vehicle. We've found that over a short duration this was a linear, or approximately linear, relationship. So, for a reconstruction, we take the static deflection that was measured from the actual hood and bounded it purposely with two tests. For example, on a reconstruction here, we drew a line connecting the two points. The value listed here .078 inches was from an actual reconstruction hood that a pedestrian actually hit. So we estimated the impact energy.

Q. But you get these two points by full scale reconstruction?

A. Yes, that's correct. I would like to point out that we then impose realistic bounds on our estimates before we continue. We know that there are various combinations of mass and velocity that will give us that energy but we make an arbitrary guess of the expected impact energy.

Q. Mike Walsh
If I'm not mistaken, on your last graph where you were showing the 15 percent probability of death for that configuration between like 2 1/2 - 3 inches, weren't there three triangles up there around 30 percent also? There seemed to be three triangles right above that at 30 percent. How do you explain that?

A. That's correct. The particular combination of radius, length and angle produce a 30 percent set as well as a 15 percent set but since we made a significant injury reduction down at 15 percent. I simply highlighted the ones at 15 percent.

Q. Tarriere
A doubt exists for me, when you said as an answer: "yes, I have a full scale reconstruction". Was it a reconstruction with a dummy, full scale reconstruction of the car involved in the actual accident with the dummies?

A. It was a reconstruction using our head impact simulator. We didn't use a dummy, we simply impacted the head with the simulator.

Q. Yes, but my question is, to have good apparent mass and the right head impact velocity, for a reconstruction with an impactor, you need to know what happened in the actual case with the real victim. You could do the full scale reconstruction, first with the dummy to get these parameters and then see if you could obtain the same results with an impactor. Instead of the full scale dummy you could also use a mathematical model that could give you the same data.

A. I agree with you but why we place so much confidence in our simulator is that we have, in the past, conducted cadaver reconstructions and then duplicated the results from the cadaver head impact with our head impact simulator. Also we use MADYMO to predict impact velocities as well.

Q. Tarriere

Yes, but you cannot use data that you got with another car. You need to know the parameters for this particular car that you are reconstructing.